

APL-UW Deep Water Propagation: Philippine Sea Signal Physics and North Pacific Ambient Noise

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Award Number: N00014-13-1-009

http://www.apl.washington.edu/projects/blue_water

LONG TERM GOALS

Understand how the fundamental statistics of broadband low-frequency acoustical signals evolve during propagation through a dynamically-varying deep ocean, and how the oceanic ambient noise field varies throughout deep ocean battlespaces.

OBJECTIVES

Current models of signal randomization over long ranges in the deep ocean were developed for and tested in the North Pacific Ocean gyre. The first objective of this research is to determine the validity of these models in a region with different oceanographic features, specifically the Philippine Sea. The second objective is to continue an 18-year long experiment utilizing the North Pacific Ambient Noise Laboratory to determine whether models of oceanic ambient noise capture the spatial and temporal trends observed across the basin.

APPROACH

Philippine Sea Analysis Our approach utilizes a combination of at-sea measurements, theoretical modeling and computational simulations. Our primary measurements are two 60 h transmission exercises over a range of roughly 500 km. We transmitted the signals: the acoustic receptions (and

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 30 SEP 2013		2. REPORT TYPE		3. DATES COVERED 00-00-2013 to 00-00-2013	
4. TITLE AND SUBTITLE APL-UW Deep Water Propagation: Philippine Sea Signal Physics and North Pacific Ambient Noise				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Washington, Applied Physics Laboratory, 1013 NE 40th St, Seattle, WA, 98105				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 17	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

associated receiver details) are provided by Worcester at Scripps, and the environmental measurements at the receiver provided by Colosi at the Naval Postgraduate School. One exercise used the HX554 source and a signal with carrier frequency 81.88 Hz, and the other used the MP200 source and two simultaneous signals with carriers at 200 and 300 Hz. Ganse is processing the MP200 data. Each MP200 signal had its own m-sequence law, allowing complete separation of the two signals in code space. Henyey provides critical guidance in our theoretical approach. Here, we assume the acoustic wave equation is valid, and use Monte Carlo simulations as guides — and benchmarks — for analytical expressions describing the evolution — i.e., the “physics” — of statistical properties of the acoustic wavefield. To attain the “applied” objective of accurately predicting at-sea performance, Henyey also provides guidance in the specification of “good” oceanographic models. Two examples are provided below.

North Pacific Ambient Noise Laboratory (NPANL) Our primary approach involves continued support for several ambient noise collection protocols, involving single and multi-channel data acquisition 24/7/365 except for outages, on APL computers located at a remote facility. The hydrophones are located in the North Pacific basin. All of our modeling to date uses OAML’s Dynamic Ambient Noise Model (DANM), generally in classified mode (in order to take advantage of advanced bathymetric and sea-bottom composition models), operating in our classified data processing facility at APL.

WORK COMPLETED

Philippine Sea Analysis

- The multi-port source [1] has two acoustic resonances at approximately 200 and 300 Hz. To accommodate those resonances in this experiment, two M-sequence signals at 200 and 300 Hz were summed together; the 200 Hz signal was labeled “red” and the 300 Hz one labeled “violet”. Due to effects of the power amplifier and transducer in the water upon the source spectrum, and noise in the long-range receptions, post processing was required on this data. Two “post-equalization” Wiener filters were designed. These filters were based on source-monitoring receptions of the transmission on a hydrophone 20m from the source, similar to the post processing on the 2009 Philippine Sea receptions [2]. Fig. 1 shows examples of signal spectra before and after the filtering of the red signal, for both source-monitor data and data received on the DVLA 500 km away. For demonstration and verification, one sees an idealized processing case on the source monitor data which had virtually no noise. But even with the high level noise on the DVLA reception at 500 km, the processing successfully enhances the original signal in the data. The improvement is also demonstrated in a time-domain plot of a distorted pulse-compressed arrival, whose spread is much reduced.
- A significant feature of our simulation approach is a new model of internal wave displacements which is faster than the standard model, and also does not rely on the WKB approximation, a feature which renders it more accurate in accounting for the influence of the lower IW modes. An output from a validation test is shown in Fig. 2. This model is described in an APL Technical Memo [3].
- Andrew cleaned up the source code package for Stan Flatté’s CAFI program and resubmitted it to the OA Library website <http://oalib.hlsresearch.com>, maintained by HLS Research, La Jolla, CA, for use by the broader ocean acoustics community. [4].

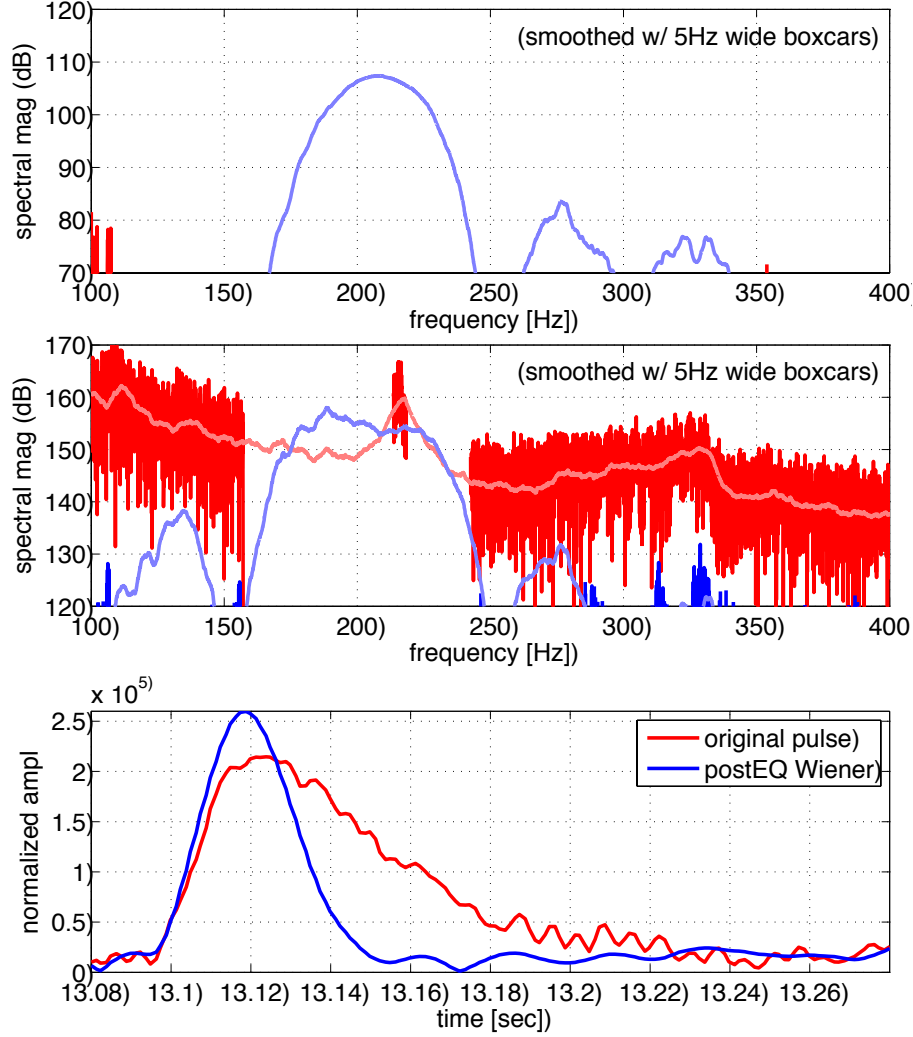


Figure 1: Spectra and pulse-compressed timeseries of received signal, both before (red) and after (blue) post equalization on the 200 Hz signal. The top plot shows the post equalization applied to the reception at the source monitor hydrophone (20m above the source). The middle plot shows the post equalization applied to the reception on 1st hydrophone at 211m depth on the DVLA (500 km away, thus with much more noise). In both the top and middle plots, overlaid smoothed versions of the spectra allow to better compare the equalization effects more easily. The bottom plot shows the reduction in pulse spread that the post equalization filter provides on the first arrival on hydrophone 001 on the DVLA.

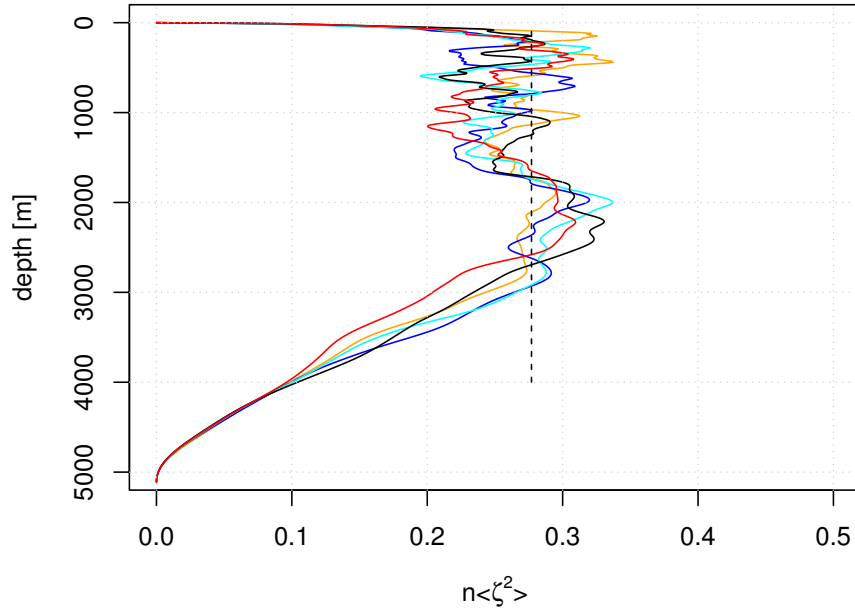


Figure 2: Validation test output for the Henyey-Reynolds internal wave simulator [3]. The curves are sample estimates of the product $n(z)\langle \zeta^2 \rangle$ of vertical displacement variance and the Brunt-Väisälä frequency versus depth. Each curve used a different random seed. The WKB result of 0.28 is shown by the dashed line. Simulation test parameters: Brunt-Väisälä frequency is the canonical Munk profile with scale depth 1300 m and surface extrapolated frequency of 3 cph; latitude 20° , 100 horizontal wavenumbers logarithmically spaced from $2\pi/10^5$ to $2\pi/10^2$ rads/m; 80 modes; modal bandwidth 3.

North Pacific Ambient Noise Laboratory

- Significant up-front effort was required to re-establish robust and reliable telecommunications between APL and our equipment at the remote facility. IT2 Cooper/NOPFWI was instrumental in helping us diagnose and correct problems with our Omni modems.
- Significant quantities (roughly 294 GB) of back-logged data (basically 2009-present) were retrieved from the remote computers and are queued up for post-processing. Post-processing at our classified Data Center has been delayed awaiting completion of the authorizing contract N00014-13-P-1222.
- A remote site data collection computer was “re-purposed” for data archiving in our Data Center. We attempted to use the “1000-year” M•DISC DVDs manufactured by Millenniata[5] for “permanent” archival storage. These discs do not use dyes for data encoding, as do all other over-the-shelf DVDs and CDs, but instead encode data with laser-etched pits. The US Army found in tests that the M•DISCs outperformed all other optical media in retaining data in harsh environment tests [6]. To date, however, we have found that rereading these encoded discs is problematic, a problem which has been noted by others on the Internet. Millenniata has not responded to this problem (to our knowledge.)
- An undergraduate physics student, Mr. Michael Svien, was hired to analyze the back-logged spectral data and conduct DANM simulations. Mr. Svien is an Air Force veteran with a TS clearance: some selected results produced so far are described below.
- An undergraduate EE student, Mr. Brian auf der Sprunge, was hired to check-in some instrumentation retrieved from the remote site, build a GPS clock redriver for our remote system racks, and develop an upgraded multi-channel sampling program based on a successful transmit-and-receive application written for the PhilSea2010 experiment.
- We sent the one-month median one-third-octave levels for 4 NPANL sites (previously published in graphical form[7]) to Dr. Michael Ainslie, TNO, for his further analysis, which resulted in a technical paper [8].
- A simple website was established to provide a high-level overview of experiment conditions. Three webpages were built, showing (1) remote computer up-times, (2) current status of the data archive, and (3) current system bugs needing attention. These pages are served over the Internet from APL, and thus are available to us even when on travel, but are “hidden” from normal web crawlers. Sample screenshots are shown in Fig. 3.
- We negotiated an MOA between the UW and NOPFWI regarding our data collecting operations located in their spaces.

RESULTS


Philippine Sea Analysis

- Henyey has developed a method to differentiate the contribution of buoyancy-compensated (i.e., “spice”) sound speed fluctuations from buoyancy-driven (i.e. internal waves) sound speed fluctuations using a single CTD cast. (Traditionally, this has been accomplished with moored data only.) It is commonly assumed in oceanography that the density ρ differs from the reference

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Current dataset locations:

System	Time Span	Location	Next Step
D	1994.11.21 - 2001.01.26	PtSur#0-D, Spindle #1, D0003_PTS - D0046_PTS	None
E	1995.07.30 - 2004.10.02	SanNic#0-E, Spindle #1-2, E0001_SNO - E0046_SNO RECLASS	None
J	" "	" "	" "
J	2009.06.15 - 2009.09.26	blueserver:/mnt/bigdisk/npnl/whidbey/j/0112_WB0	erase after write
J	2009.06.15 - 2009.09.26	skellia:~/tmp/j/0112 WB0	complete, no errors, write to DVD
J	2009.09.27 -		
J	2009.09.27 -		
J	2011.03.11 -		
J	2011.03.11 -		
J	2011.05.30 -		
J	2011.05.30 -		
J	2009.06.15 -		
K	2009.06.15 -		
L	2009.06.15 -		



Logged in as: rex (Rex - manager) 2013-08-17 16:07 PDT

[Main](#) | [My View](#) | [View Issues](#) | [Report Issue](#) | [Change Log](#) | [Roadmap](#) | [Summary](#) | [Manage](#) | [My Account](#) | [Logout](#)

Assigned to Me (Unresolved) [^] (1 - 2 / 2)

0000048	[npnl-problems] Need hard drive logging procedures [All Projects] General - 2013-05-24 10:03
0000048	[npnl-problems] site 3 IRIG problems [All Projects] General - 2013-05-24 10:02

Unassigned [^] (1 - 10 / 20)

0000042	[npnl-problems] npal05 cannot mount RHDs [All Projects] General - 2012-11-30 15:35
0000041	[npnl-problems] npal06 needs SW upgrade [All Projects] General - 2012-11-30 15:35
0000040	[npnl-problems] Cannot read RHDs [All Projects] General - 2012-11-30 15:34
0000039	[npnl-problems] unity down [All Projects] General - 2012-11-30 15:34
0000038	[npnl-problems] SiteJ archive data [All Projects] General - 2012-11-30 15:33
0000037	[npnl-problems] SiteP archive data [All Projects] General - 2012-11-30 15:32
0000036	[npnl-problems] SiteN archive data [All Projects] General - 2012-11-30 15:32
0000035	[npnl-problems] SiteO archive data [All Projects] General - 2012-11-30 15:31
0000031	[npnl-problems] Stricter control on drive media at NOI [All Projects] General - 2012-11-30 15:28
0000030	[npnl-problems] npal08 needs SW upgrade [All Projects] General - 2012-11-30 15:26

Current system status:

System	Host	Uptime	Last Accessed	Notes
J	npal16	27 days	Mon Aug 12 19:10:58 UTC 2013	OK
K	npal18	11 days	Mon Aug 12 19:11:37 UTC 2013	OK
L	npal06	26 days	Mon Aug 12 19:11:55 UTC 2013	OK
M	npal17	26 days	Mon Aug 12 19:12:11 UTC 2013	OK: timeserver only
N	npal11	26 days	Mon Aug 12 19:12:28 UTC 2013	OK
O	npal15	8 days	Mon Aug 12 19:12:45 UTC 2013	OK
P	npal02	26 days	Mon Aug 12 19:13:04 UTC 2013	OK
T	npal07	27 days	Mon Aug 12 19:13:23 UTC 2013	OK

Page built 2013.08.17 at 09:05:01 UTC

Figure 3: Screenshot overlays of NPANL experiment webpages, providing information on the current status and location of datasets (background), a “bug tracker” for posting and resolving maintenance issues (middle ground) and remote host operational status (foreground).

background profile ρ_0 by the density displacement ζ_ρ times the nonadiabatic density gradient:

$$\rho - \rho_0 = \delta\rho = \zeta_\rho \left(\frac{\partial \rho_0}{\partial z} \right)_{na} \quad (1)$$

An analogous relation using sound-speed is assumed in ocean acoustics:

$$c - c_0 = \delta c = \zeta_c \left(\frac{\partial c_0}{\partial z} \right)_{na} \quad (2)$$

Both equations are solved for the displacements. Given only a single CTD cast, some crude approximations are required for solution quantities: the reference profile and the fluctuation are constructed, respectively, from the low- and high-pass filtered density or sound speed derived from the cast. The displacement ζ_ρ is due to internal waves, but ζ_c is due to internal waves *and* spice. The spectrum of ζ_c would be equal to that of ζ_ρ in the absence of spice, but elevated when spice is present. Assuming the internal waves and spice are statistically independent, one has a consistency check that the cross-spectrum between ζ_c and ζ_ρ should equal the spectrum of ζ_ρ , [because the cross-moment between internal waves and spice is zero.] These results are more conveniently displayed as vertical derivatives of ζ_ρ and ζ_c , i.e., the vertical density and sound-speed strain.

During the 2010 Philippine Sea experiment, 51 CTD casts were taken along a 500 km line. The data were processed, as outlined above, to extract the component due to internal waves and the component due to both internal waves and spice. A summary of the results is shown in Fig. 4. The left panel shows the average spectra over the western 120 km of the path, while the right panel shows the average over the entire 500 km. In the western portion, the internal wave spectrum is about twice the Garrett-Munk (GM) level. The spice contribution, indicated by the elevation of the sound-speed strain level over the density strain level, is only about 15% of the internal wave contribution. Averaged over the entire path, the internal wave spectrum is about 1.6 times the GM level, while the spice spectrum is 50% of the internal wave spectrum. Coincidentally, the total sound speed spectral level is about the same in the western and entire averages. The internal wave values can be compared to larger vertical scale results [9] from a year-long mooring in the same area, which yielded a 1.5 GM level. Similar analyses were done for smaller data sets from two previous experiments. In the central and eastern north Pacific, the internal wave level was found to be about one-half GM, consistent with previous larger-scale estimates, and the spice contribution was about equal to the internal wave contribution.

We can conclude that the internal wave level was higher than “one GM” in the Philippine Sea, but lower than one GM in the central and eastern north Pacific — a result that is consistent with the GM level estimate extrapolated from larger scales — and that spice is not likely to be a lot less important for acoustics than internal waves.

We are preparing a journal paper on these results.

- We expanded our calculations of *a posteriori* acoustical intensity fluctuations at 284 Hz (namely log-amplitude variance) using Munk-Zachariasen theory ([10], hereafter MZ76). Earlier calculations used 3 eigenrays — ID−3, ID+4 and ID−4 — terminating at a depth of 1550 m at a range of 107 km. Predictions were compared to at-sea measurements produced by Dr. Andrew White, APL -UW.

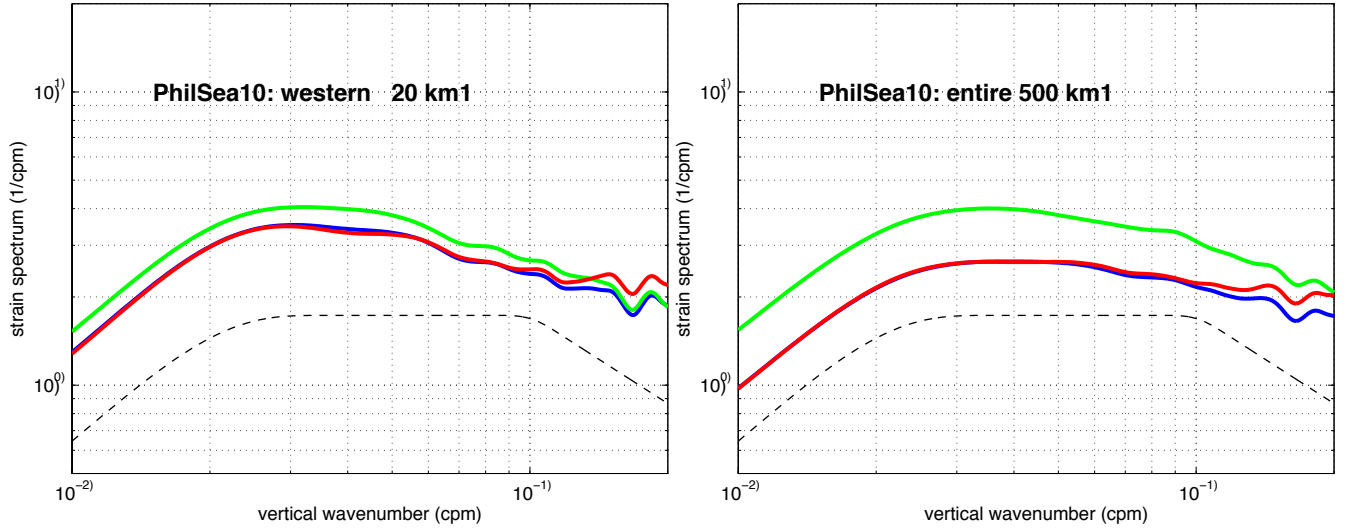


Figure 4: Strain autospectra for density (red) and sound-speed (green) and their cross-spectra (blue) for the Philippine Sea, determined by CTD casts. The left panel shows the average spectra over the western 120 km of the path, while the right panel shows the average over the entire 500 km. The dashed line is the “one GM” density strain spectrum [15], modified at low-wavenumbers so as to represent the filtering applied to the CTD data. The western path has roughly 2 GM level (red curve) but little extra contribution from spice (green curve). The average over the full path, which is the channel for the APL 500 km transmissions, appears to have only about 1.6 GM (red curve), but a considerably larger contribution from spice (green curve). In both cases, the cross-spectrum (blue) mirrors the the density-driven curve (red) almost everywhere, verifying that the underlying buoyancy-driven and buoyancy-compensated processes are stochastically independent.

White has now expanded his measurements to include several dozen eigenrays with 3 turning points, 4 turning points, and 5 turning points, terminating at multiple depths from 600 m to 1650 m at 107 km range [11]. He has also included corresponding Monte Carlo PE computations.

We therefore ran calculations for similar eigenrays to 107 km. The results are shown in Fig. 5. This is the first complete comparison of analytical theory versus Monte Carlo PE versus actual at-sea measurements ever made at these frequencies. The results suggest that the MZ76 theory is slightly low for wavefields throughout the sound channel, independent of whether the path involved 1, 2 or 3 upper turning points. Previous results were overly optimistic, and were based only on comparisons at about 1550 m, where data and MZ76 theory seemed to correspond much better.

We are preparing a journal paper on these results.

- APL-UW's dual-band, 500 km transmissions from the ship-suspended, multi-port source in the 2010 Philippine Sea experiment present a unique opportunity to analyze long-range, low-frequency scattering in widely separated frequencies transmitted simultaneously. The mechanism behind the deep fades observed in these long-range ocean acoustic arrivals is still not well understood by the ocean acoustics community. Analysis of the frequency dependence (or lack thereof) of their statistics is providing evidence that conflicts with the prevailing theoretical explanation for their cause.

The dual-band signal was transmitted for 60 hours, and received on the SIO distributed vertical line array (DVLA) with 149 working hydrophones spaced over most of the water column [12]. Filtering with the post-equalizer significantly reduces the pulse spreading caused by the transfer functions of the amplifier and transducer in water, as seen in Fig. 6. This figure shows results for one M-sequence of the red signal (the violet signal has similar but less pronounced improvement).

Initial processing results of the PhilSea2010 data show deep fades in both frequency bands, i.e. frequency-dependent variations of 10-20 dB in acoustic arrival intensities on the DVLA (see Figure 7). Strong correlations are visually apparent in the fades at the two frequency bands and no arrival splitting is seen so far in the wavefront data. These two features are two manifestations of the same phenomenon and conflict with the established theory for the cause of deep acoustic fading in the ocean [13]. We note that in addition to this deep water case, a similar conflict was recently observed in a shallow water experiment as well [14]. In our work, statistics of the acoustic intensity fluctuations are being calculated for all the data in both frequency bands. Cross-band statistics for the complete dataset will provide more rigorous evidence against the role of internal-wave induced arrival splitting as the causative agent in the deep fades observed in this experiment.

North Pacific Ambient Noise Laboratory

- Initial analysis of low-frequency time-series from multiple receiver locations throughout the north Pacific are demonstrating an unexplained spatial dependence in the linear temporal trends.

We have recently reported linear trends over the timespan of roughly 1994-2007 for four receivers situated along the north American west coast [7]. The observed trends are much weaker than were postulated in the literature in the middle of the last century, and, at the two most northern sites the trends over the last decade are decreasing.

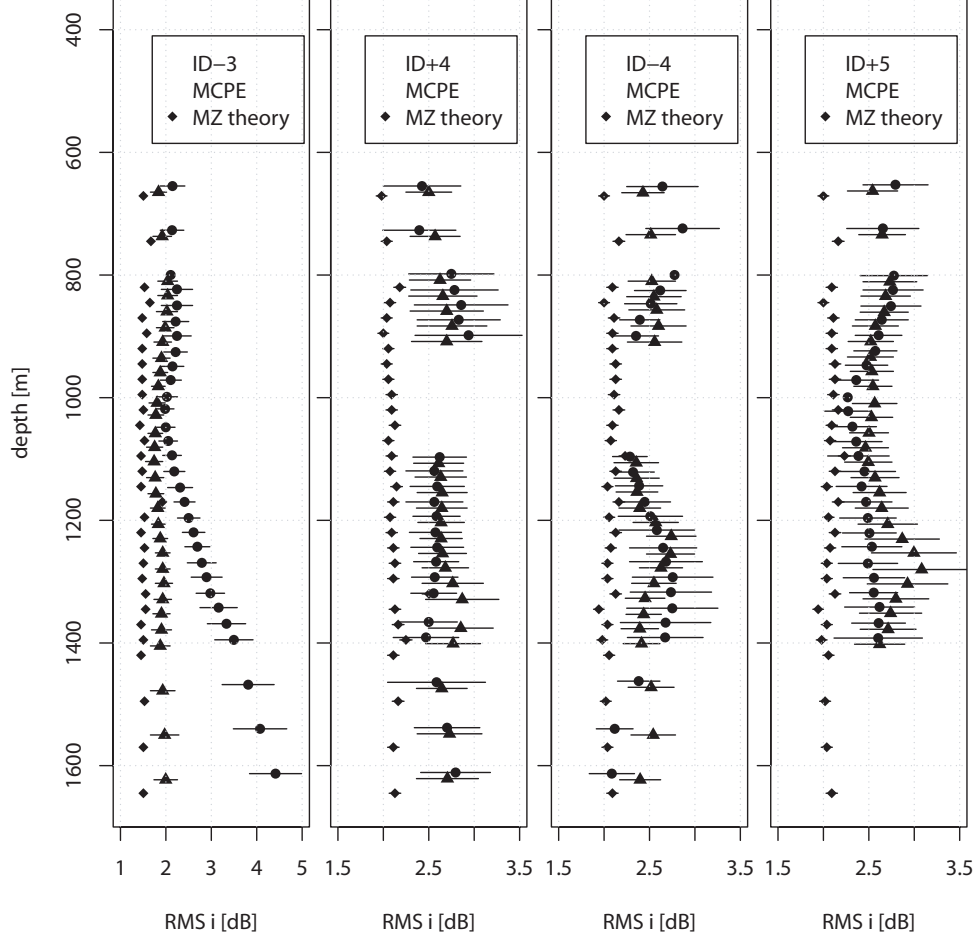


Figure 5: Comparison of the variance of log-intensity, using Munk-Zachariasen theory, Monte Carlo PE predictions[11], and measurements[11] made during PhilSea 2009 for four 107 km acoustic paths from projector to receiver at 284 Hz. Path ID–3 had one upper turning point, paths ID–4 and ID+4 both had two upper turning points, and path ID+5 had three upper turning points. Horizontal bars represent standard errors deduced from figures shown in White et al [11]. Both the Munk-Zachariasen and Monte Carlo calculations are a posteriori estimates because they incorporate ocean parameters estimated using PhilSea 2009 environmental measurements. The deviation of measurements from either MCPE or MZ predictions for path ID–3 below about 1100 m is due to oceanography not represented in the Garrett-Munk internal wave model.

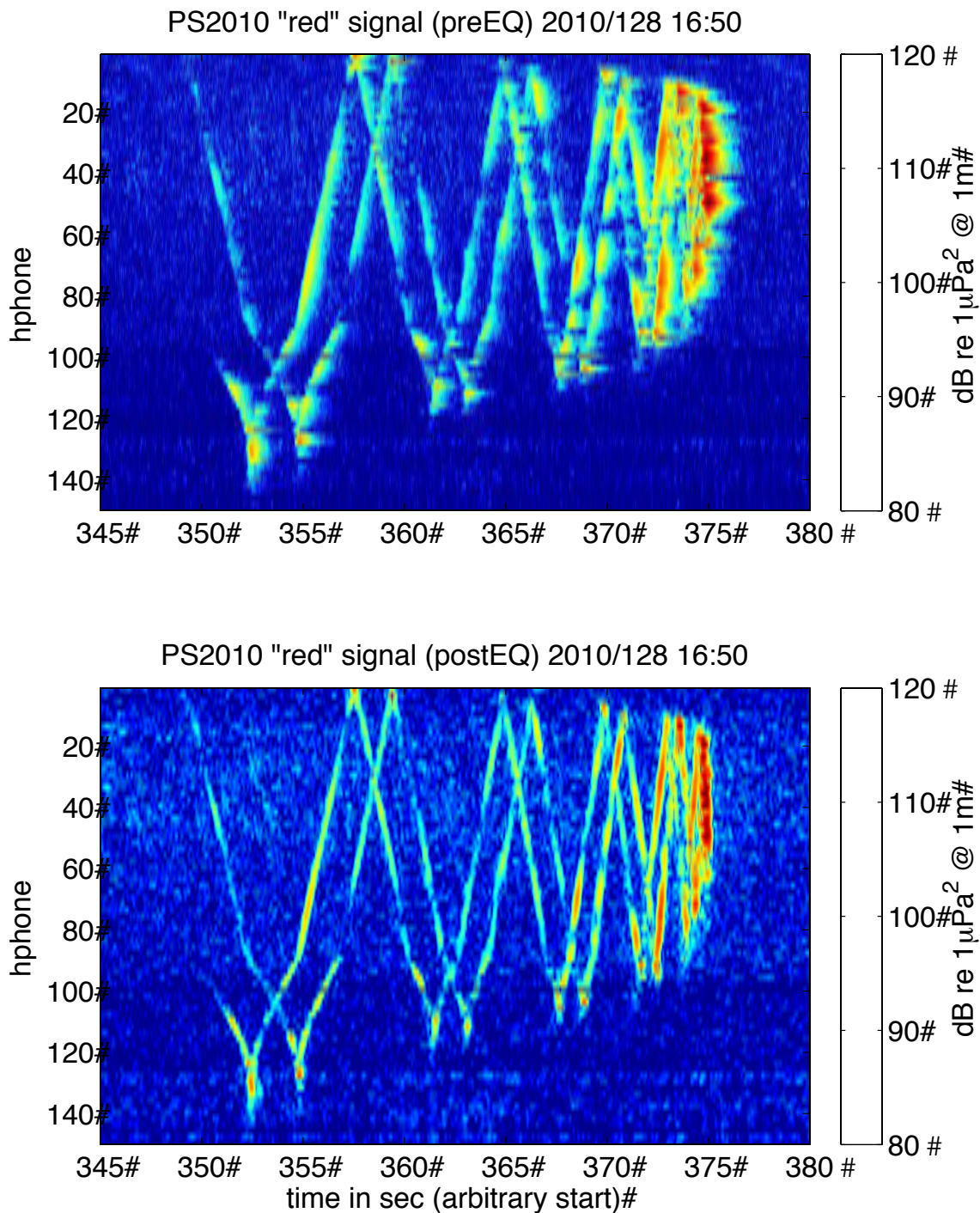


Figure 6: Wavefront received at DVLA before (top) and after (bottom) application of the post equalization filter to significantly reduce pulse spreading in the arrivals. This example is for the lower frequency or red signal (200 Hz). Note the vertical axis is hydrophone number rather than depth, which accounts for the sudden slope changes in the arrivals where the hydrophone spacing changed. This is the first m-sequence in the transmission started at 16:48:10 on year day 128 (for which reception at DVLA started at 16:50:15).

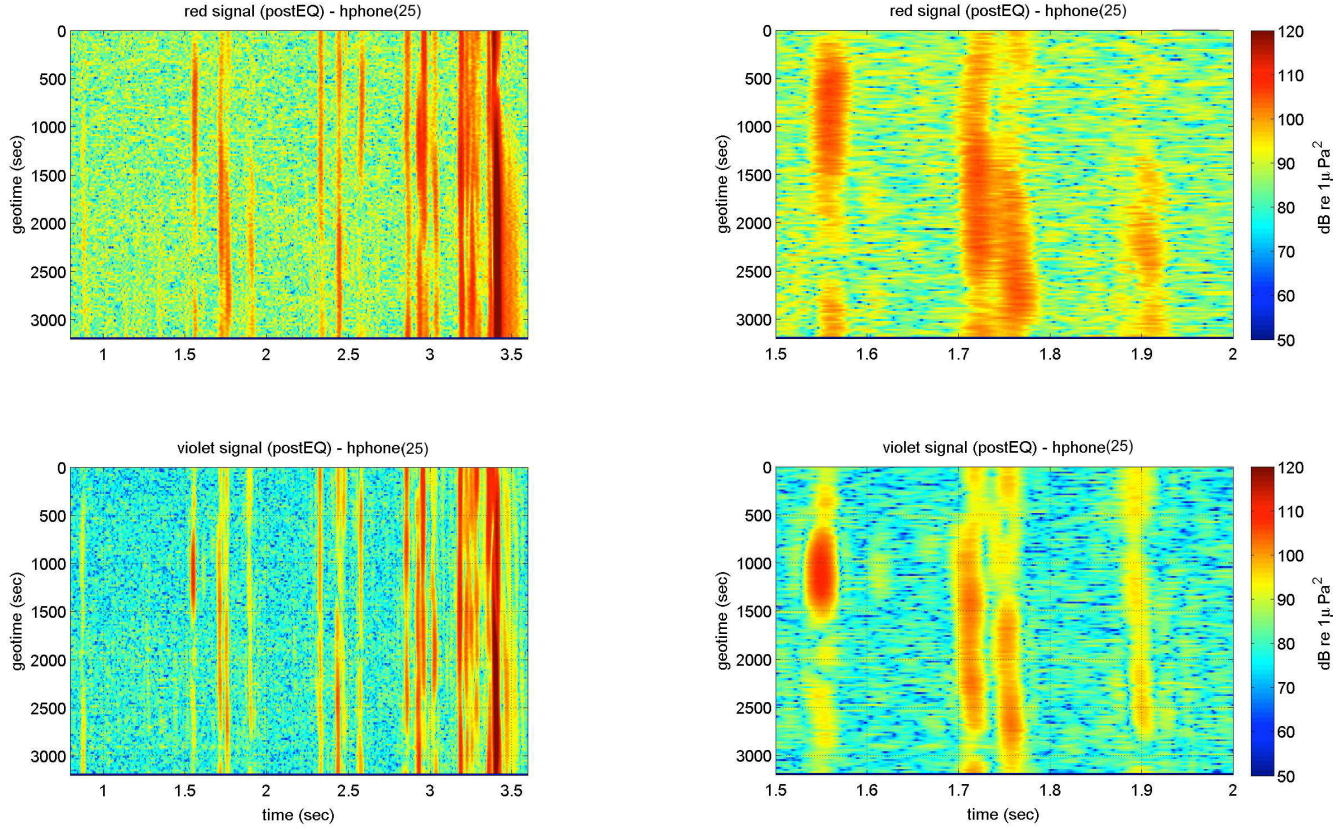


Figure 7: Evolution of intensity of arrivals on 25th hydrophone at 890m depth on the DVLA over the hour of “geotime” starting at 16:50:15 (see Fig. 6), in both the red (200 Hz) signal and violet (300 Hz) signals which were transmitted simultaneously. Plots in top row represent the red signal and those in bottom row represent the violet signal. Plots in right column are zooms of the four prominent arrivals between 1.5-2.0 sec in left column plots. In both the left and right plots, deep fades are seen in the intensity of the arrivals over the hour. These fades are seen to be largely correlated between the two widely separated frequency bands and no arrival splitting is seen thus far.

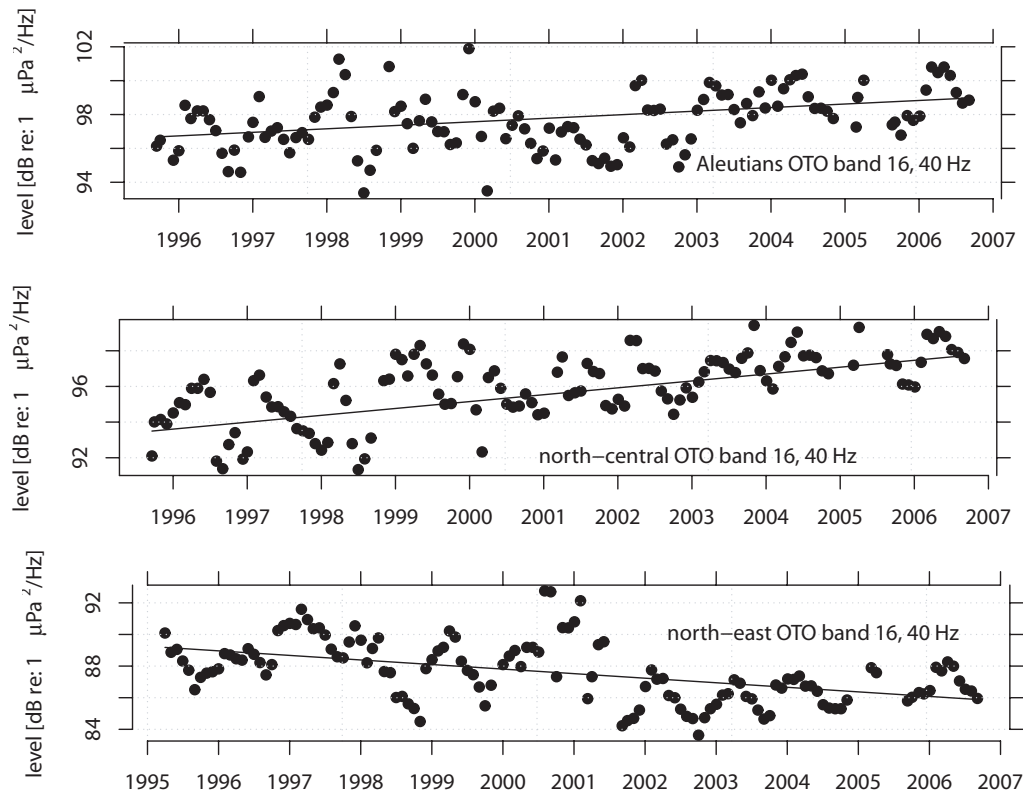


Figure 8: Ambient noise levels from locations near the Aleutian islands (top panel), the north-central Pacific basin (middle panel) and the north-eastern Pacific basin (bottom panel.) Each point represents the average over a month at one-third-octave band 16 (centered at 40 Hz). The lines are least-squares fits to the points. The abscissa is the year. Increasing trends are intuitively consistent with the number of ships in the world merchant fleet, which is increasing year-to-year. Decreasing trends are anomalous, but consistent with coastal measurements previously reported [7].

Our current efforts have revealed similar unexplained anomalies in seven previously unprocessed datasets for receivers situated throughout the northern Pacific Ocean. Trends for the 40 Hz one-third-octave band levels (one of the main shipping traffic noise bands) for three of these systems are shown in Fig. 8. Receivers located along the Aleutian islands and distributed down through the north-central Pacific show an increasing trend in noise levels associated with maritime shipping — as is commonly expected, due to the well-known year-to-year increase in the number of merchant ships in the world’s fleet — but receivers located in the eastern basin show a decreasing trend, as was reported earlier [7].

Neither the temporal trends nor the geospatial patterns are currently understood. Attempts to simply scale up DANM calculations from 1998 merchant fleet size to 2007 merchant fleet size did not reproduce the increase observed along the Aleutians nor in the north-central Pacific. Of course, the decrease seen in the three north-eastern receiver datasets, which corresponds to the feature seen in the northerly CONUS coastal systems, remains completely unexplained.

IMPACT/APPLICATIONS

- The Philippine Sea provides more scattering than does the eastern north Pacific, where we have previously conducted long-range low-frequency acoustic experiments. While we suspected this, some of our models (the internal wave contribution based on density alone, or the MZ76 theory) continue to under-estimate the scattering strength, which will cause predictions of sonar and long-range acoustic communication performance to be overly optimistic in this regime.
- The decrease in apparent measured noise levels for the north-central Pacific observation stations could be attributed to gradually deteriorating in-water hardware. One would assume that hardware degradation would be of considerable interest to the U.S. Navy. If, after more thorough analysis (we have two additional acoustic channels to check at each station, and data from 2008 to present to process as well), these north-eastern level anomalies persist in the observed data, it might be germane to mount an at-sea calibration effort.

RELATED PROJECTS

- Our deep water propagation efforts involve collaborations with Art Baggeroer (MIT), Michael Brown (UM), Bruce Howe (UH), John Colosi and Tarun Chandrayadula (NPS), Vladimir Ostashev (NOAA/ETL), Ralph Stephen and Ilya Udovydchenkov (WHOI), Alexander Voronovich (NOAA/ETL), Kathleen Wage (GMU) Peter Worcester (SIO), and Hee-chun Song and Gerald D’Spain (MPL). In particular this year we have been exchanging hydrophone array instrumentation and oceanographic mooring data products with Worcester and Colosi.
- Our investigations into the nature of oceanic ambient sound have brought us into a collaboration with Dr. Leila Hatch (NOAA Stellwagen Bank National Marine Sanctuary) and the NOAA Underwater Sound Field Mapping Group: Brandon Southall (Southall Environmental Associates); Christopher Clark (Cornell); Christian de Moustier, Michael Porter, Laurel Henderson (HLS Research, Inc.); Kurt Fristrup (Natural Sounds Program Center, National Park Service); Jason Gedamke (NOAA Fisheries Office of Science and Technology); Shane Guan, Amy Scholik-Schlomer (NOAA Fisheries Office of Protected Resources); Ronald Brinkman, Brian Hooker (Bureau of Ocean Energy Management, Regulation, and Enforcement); Carrie

Kappel (National Center for Ecological Analysis and Synthesis, UCSB); David Moretti (NUWC); Roberto Racca (JASCO Applied Sciences). Most recently, we are working with Porter, Clark and Gedamke to provide (i.e., release) actual at-sea ambient sound measurements to verify the performance of the HLS ambient noise model [16].

- Our contributions to long-time trends in oceanic ambient sound have also connected us this year to Prof. Ross Chapman (University of Victoria), Dr. Michael Ainslie (TNO), Dr. Jennifer Miksis-Olds (ARL-PSU), and Prof. Michel André (Universitat Politècnica de Catalunya) regarding global long time series measurements of ambient sound. This is in some degree a follow-on to the IQOE initiative of 2011 [17], where most of us first synergized on this topic.

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PUBLICATIONS

This year saw a substantial effort by all the NPAL collaborators to produce a special issue on deep water acoustics for the Journal of the Acoustical Society of America (scheduled possibly for October 2013). Those papers (and others) involving either Andrew or Henyey as author or co-author this year are listed below:

- [1] HC Song, BM Howe, MG Brown, RK Andrew, “Diversity-based acoustic communication with a glider in deep water (L)”, *J. Acoust. Soc Am.* (submitted August 2013.)
- [2] WSD Wilcock, KM Stafford, RK Andrew, RI Odom, “Sounds in the Sea at 1-100 Hz”, *Ann. Rev. Mar. Sci.* [in press].
- [3] AW White, RK Andrew, JA Mercer, PF Worcester, MA Dzieciuch, and JA Colosi, “Wavefront intensity statistics for 284-Hz broadband transmissions to 107-km range in the Philippine Sea: observations and modeling I”, *J. Acoust. Soc Am.*, (JASA special issue on deep water acoustics) [in press].
- [4] TK Chandrayadula, JA Colosi, PF Worcester, MA Dzieciuch, JA Mercer, RK Andrew, and BM Howe, “Observations and transport theory analysis of low frequency, long range acoustic mode propagation in the Eastern North Pacific Ocean”, *J. Acoust. Soc Am.* (JASA special issue on deep water acoustics) [in press].
- [5] TK Chandrayadula, KE Wage, PF Worcester, MA Dzieciuch, JA Mercer, RK Andrew, and BM Howe, “Reduced rank models for travel time estimation of low mode pulses”, *J. Acoust. Soc Am.*, (JASA special issue on deep water acoustics) [in press].
- [6] RA Stephen, ST Bolmer, IA Udovydchenkov, PF Worcester, MA Dzieciuch, RK Andrew, JA Mercer, JA Colosi, and BM Howe, “Deep seafloor arrivals in long range ocean acoustic propagation”, *J. Acoust. Soc Am.*, (JASA special issue on deep water acoustics) [in press].
- [7] IA Udovydchenkov, MG Brown, TF Duda, PF Worcester, MA Dzieciuch, JA Mercer, RK Andrew, BM Howe, and JA Colosi, “Weakly dispersive modal pulse propagation in the North Pacific Ocean”, *J. Acoust. Soc Am.* , (JASA special issue on deep water acoustics) [in press].

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- [10] IA Udovydchenkov, RA Stephen, TF Duda, ST Bolmer, PF Worcester, MA Dzieciuch, JA Mercer, RK Andrew, and BM Howe, "Bottom interacting sound at 50 km range in a deep ocean environment", *J. Acoust. Soc. Am.*, **132**, pp 2224-2231 (2012), [published,refereed].
- [11] IA Udovydchenkov, MG Brown, TF Duda, JA Mercer, RK Andrew, PF Worcester, MA Dzieciuch, BM Howe, and JA Colosi, "Modal analysis of the range evolution of broadband wavefields in the North Pacific Ocean: Low mode numbers", *J. Acoust. Soc. Am.*, **131**, pp 4409-4427 (2012), [published,refereed].

AWARDS/HONORS/PRIZES

- Andrew: Letter of Appreciation from Dr. D. Bradley, President, Acoustical Society of America, for participation in the Technical Program Organizing Meeting (TPOM), Montréal International Congress on Acoustics, February 2013.
- Ganse: Doctor of Philosophy, Department of Earth and Space Sciences, University of Washington. Dissertation: *Uncertainty and Resolution in Full-Waveform, Continuous, Geoacoustic Inversion*.
- Henyey: Acoustical Oceanography technical committee of the Acoustical Society of America, term 2012-2015.
- Andrew: Appointment to the Acoustical Oceanography technical committee of the Acoustical Society of America, term 2013-2016.